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PROJECT BRIEF

EMIRATE OF ABU DHABI

ASSESSMENT OF SEISMIC HAZARD AND RISK

PROJECT OBJECTIVE

Develop a state-of-the-art system to assess, monitor, mitigate, and update the seismic hazard and risk in the Emirate of Abu Dhabi

PROJECT ACHIEVMENTS

Our project objective is achieved via a multifaceted approach involving not only ground observations and geologic studies, but also Structural Health Monitoring Systems in representative tall buildings, and culminating in a Real-Time Seismic Monitoring and Management Center.

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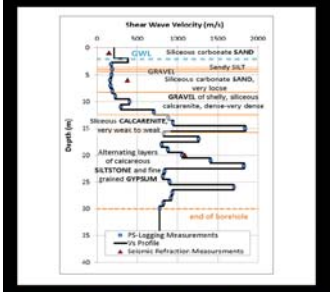
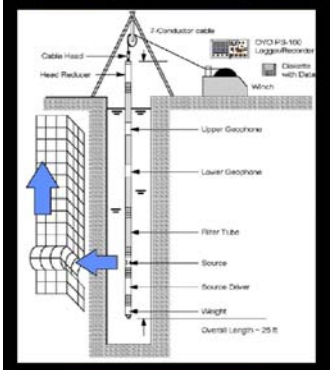
To assure sustainable development of the Emirate of Abu Dhabi (UAE), and cultivate a disaster-free living environment for its citizens, the Abu Dhabi Municipality initiated the project "Assessment of Seismic Hazard and Risk in Emirate of Abu Dhabi". The primary objective of the project is to quantify and assess the seismic hazard and risk that exists for the Emirate of Abu Dhabi. This is achieved via a multifaceted approach involving not only ground observations and geologic studies, but also Structural Health Monitoring Systems in representative tall buildings, and culminating in a Real-Time Seismic Monitoring and Management Center. The table below is an abbreviated list of project tasks:

TASK	TASK DESCRIPTION
01	Seismic Zoning
02	Site Amplification & Microzonation
03	Liquefaction Susceptibility Study
04	Seismic Design Parameters
05	Risk Analysis of Lifelines
06	Risk Analysis of Critical Structures
07	Permanent Accelerograph Network
08	Seismic Monitoring Network
09	Ground Shaking Map
10	Structural Health Monitoring
11	3D Seismic Simulation Model
12	Risk Analysis of Tall Buildings
13	Loss Estimation
14	Data Management Centers
15	GIS Seismic Database
16	Coordinated Activities
17	Promotion & Public Awareness
18	Training
19	Build, Operate, and Transfer (BOT)
20	Maintenance





SEISMIC HAZARD, MICROZONATION, AND RISK ASSESSMENT

The Seismic Risk Assessment examined the seismic vulnerability, performance, and risk of Critical Life Line Structures (electric power, water supply, gas transportation, and oil transportation systems), and identified the risk level inherent to current design and construction practices within the Emirate of Abu Dhabi. Site Amplification, Liquefaction, and Microzonation studies were conducted to estimate the influence of local soil conditions upon the amplitude and frequency content of regional seismic events.

A seismic source model for the UAE region was developed based on the tectonics, seismicity and topographic features of the region, comprised of three areal active shallow regions; a linear source zone, a subduction zone, and a background zone, with recurrence intervals determined from historical and instrumental seismicity. Ground Motion Prediction Equations (GMPEs) were developed based on three distinct tectonics regimes surrounding the UAE: a stable continental region, an active shallow region, and a subduction zone. Probabilistic (PSHA) and Deterministic (DSHA) Seismic Hazard Assessments were conducted to define and map Design Ground Motion (DGM) parameters, including Peak Ground Acceleration, Peak Ground Velocity, Modified Mercalli Intensity, and 5% Damped Spectral Acceleration for both Long and Short Periods; and for Tall Building Performance Levels, including Serviceability Limit State, Damage Control Limit State/Life Safety, Survival Limit State/Collapse-Prevention, and Maximum Credible Hazard Scenario. All parameters calculated were provided to the client in map form, with the spatial distribution of the DGM parameters presented at both the UAE regional level and a finer level for microzonation studies.

SITE STUDIES

A full suite of geotechnical measurements (microtremor, seismic refraction, liquefaction analysis, borehole drilling and analysis, etc.) was conducted at each site instrumented, as well as, near three buildings equipped with Structural Health Monitoring Systems, to assess the suitability of the site. These assessments were then archived, and used to calibrate and refine data for the GIS system designed to work with the Real-Time Seismic Monitoring and Management Centers established by this project.

HARDWARE

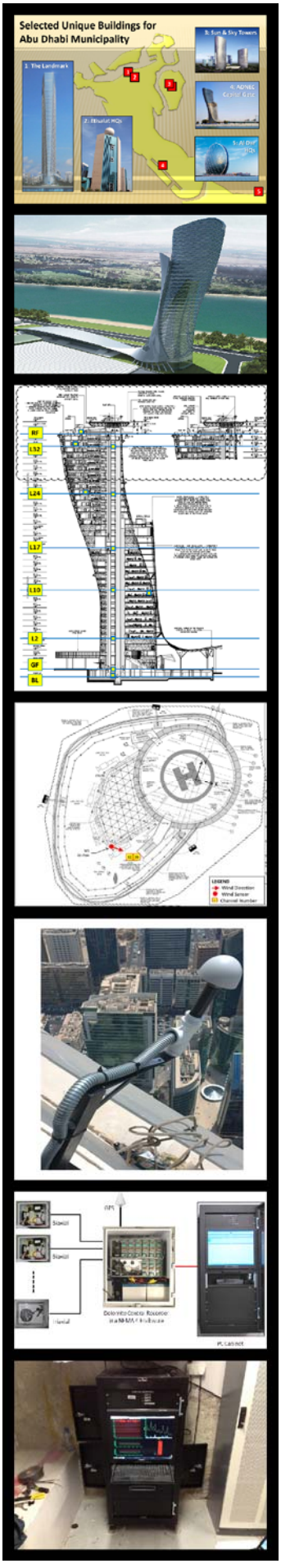
The Emirate of Abu Dhabi Permanent Accelerograph Network comprises 50 strong motion stations. Kinemetrics Shallow Borehole EpiSensors are installed at 35 free-field sites, and at an additional 5 sites accelerograph arrays are installed at both 3- and 30-meter depths. Completing the network are 10 Kinemetrics EpiSensor ES-T's installed in small buildings. All stations are equipped with Kinemetrics Basalt4x (or Basalt8x) Digitizers. Each station is equipped with GPS antennas, Raven XE 3G modems and solar panels. The stations are distributed with the intent of providing the maximum reliable coverage of the emirate and to provide robust data for the Seismic Monitoring and Management Center, with an emphasis on existing urban areas and areas currently under development. The acquired data will be used to establish parameters for structural design, verification, and calibration of current

seismic codes, as well as provide detailed lithostratigraphic and geotechnical characteristics of each site.

In addition to the accelerograph network, 4 broadband seismic stations are installed as part of the Emirate of Abu Dhabi Seismic Monitoring Network. Each station contains a broadband seismometer (CMG3T sensor) and accelerometer (EpiSensor ES-T) in order to record both velocity and acceleration data in real-time, Quanterra Q330 digitizers, and VSAT telemetry. The primary function of the broadband stations is to improve the quality of existing data for the construction of a 3D Seismic Simulation Model for the simulation of long period seismic waves and provide a better understanding of the crust and crustal fracturing processes in the region.

Seven unique structures are instrumented with state-of-the-art Structural Health Monitoring (SHM) Systems, designed to provide real-time critical information, status alerting, rapid post-event assessment, and to improve overall safety and reliability. Potentially damaging conditions, such as extreme response and fatigue, can be detected quickly after an event (e.g., an earthquake or strong windstorm).

The SHM Systems are comprised of 3 major components; sensors, a multi-channel data acquisition system, and a monitoring, display and alarm system. The sensors include a borehole accelerometer (Kinemetrics EpiSensor, SBEPI), a foundation level and 16-28 above ground floor level accelerometers (Kinemetrics EpiSensor ES-T, ES-U2), and an ultrasonic wind sensor (Gill Instruments WindObserver II). Kinemetrics' 24 or 36 channel Dolomite Central Data Recorders are used to acquire, record, and publish all real-time data. For Real-Time Structural Health Monitoring, Display, and Alerting, an industrial rack-mounted Panel-PC with an Alarm Panel is installed at each selected building. Customized SHM application software (REC_MIDS) processes, interprets and delivers SHM results in real-time to onsite building personnel and remotely to Emergency Management in the Real-Time Seismic Monitoring and Management Center.

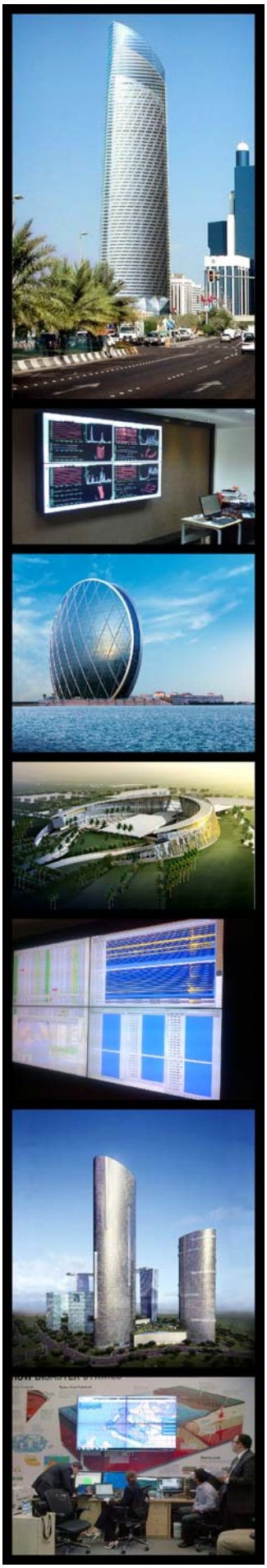


SOFTWARE

All data, acquired through the preliminary Seismic Hazard, Microzonation, and Risk Assessment studies, and newly acquired data received from the Permanent Accelerograph and the Seismic Monitoring networks, are compiled into a GIS database that will be used for rapid calculation and display of seismic and Life Line data by Emergency Management Personnel.

Kinemetrics' ASPEN™ Open System Solution is used to provide a comprehensive and integrated platform for both seismic and strong-motion networks, with both on-site archival and telemetered data streams. BRTT's Antelope™ software provides the framework with which to collect, process, and archive the critical real-time data in a robust and reliable manner. The customizable ASPEN System includes extensive network state-of-health monitoring and provides automated earthquake detections and locations in near real-time.

Kinemetrics has developed an integrated software suite that combines the USGS-written ShakeMap™ program with the ASPEN real-time system™, in order to automatically produce ground-shaking maps almost immediately following a notable earthquake in or around the UAE. The software suite produced is integrated



seamlessly into the ASPEN Real-Time Data Acquisition System and is of modular design, which allows the programs to be updated or expanded with relative ease. When an earthquake is detected and located by the UAE seismic networks, the software suite immediately attempts to download any data that was missing or not triggered from the UAE Permanent Accelerograph Network, then archives and databases the data into the real-time system and produces the Ground Shaking products using the ShakeMap code base.

Programs were written to seamlessly integrate the computation of ShakeMaps into the Antelope Real-Time System installed in the data centers. ShakeMaps are computed for every origin located by the real-time system, and the computed grid files are uploaded to a FTP server for GIS refinement (for Life Line and potential building damage estimates), and resulting web pages are published to a web server, accessible to users on the network.

LIFE LINE DISPLAY AND DATA CENTERS

The Emirate of Abu Dhabi Seismic Risk Monitoring and Management Center is a disaggregated system comprised of 2 Data Centers and 5 Display Centers. The Data Centers receive real-time data from the Permanent Accelerograph Network, the Seismic Monitoring Network, and the Structural Health Monitoring Systems. The data from the existing seismic networks of the National Center of Meteorology and Seismology in Abu Dhabi (NCMS), Dubai Municipality, Oman, and Kuwait are also integrated into the system. The GIS database and GIS application servers are located in the Data Centers. The Data Centers operate as mirror systems, and provide for redundant near real-time data acquisition of the permanent accelerograph network, the SHM systems, and all external data services. All data is concurrently brought into both Data Centers.

The 5 Display Centers are optimally located in each of the 3 Municipalities of the Emirate of Abu Dhabi (Abu Dhabi, Al Ain, and the Western Region), in the Abu Dhabi Police Headquarters, and at the NCMS main office. The Display Centers are equipped with Video Walls, which display relevant system data. The Video Walls are semi-interactive, allowing operators to quickly visualize data flow, seismic station state-of-health, REC-MIDS, any notable earthquake (as located by the automated system) and associated waveforms, and the ShakeMap and GIS web based products. Operator selectable video feeds at the Display Centers, together with the GIS and ShakeMap web-services, provide a comprehensive picture of the state of emergency in the event of a large earthquake.

Kinemetrics has streamlined the Display Centers and refined the data review process for ease of use for Emergency Management Personnel. Only pertinent information is displayed; removing the need to sift through the data for time-dependent critical information. First responders can see immediately when action must be taken. Detailed information regarding the status of Critical Life Line Structures is displayed in a context useful to first responders. Kinemetrics has also trained Emergency Management Personnel on how to access and utilize the information provided, allowing the decision makers to easily and rapidly commence with post-event procedures.

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FINAL PROJECT STATISTICS

Project Accomplishments:

- 378 channels of real-time monitoring data
- 50-station strong motion network
- 4-station broad-band network
- 7-building SHM network
- 2 redundant data centers
- 5 display centers

Work Executed:

- 80,000 man-hours worked
- 250,000 km traveled for the implementation of ADSHRA.
- 30 km of cable laid for SHM systems
- 115 work permits processed
- 2,940m of boreholes drilled for geotechnical investigations and SMN
- 15,000m of surface refraction measurements taken
- 190 sites assessed during month-long seismic noise measurements for Microzonation and site characterization

Resources Utilized:

- Project management and oversight cooperation of Geoscope & Kinemetrics
- Scientific organization (Kandily Observatory)
- 4 specialized companies (Geotechnical, GIS, Contracting and Monitoring Solution)
- Consulting support of 47 Specialists and 22 Ph.D.'s
- Dedicated project office with resident project manager and permanent staff
- 3 week-long conferences and numerous training sessions with the participation of international leaders within the scientific community